<u>Country</u>	:	Japan
<u>Document No.</u>	:	Sho 60-13283
<u>Document Type</u>	:	Kokai
<u>Language</u>	:	Japanese
<u>Inventor</u>	:	Shōichi Watanabe
<u>Applicant</u>	:	Nippon Genshiryoku Jigyo K.K.
<u>IPC</u>	:	G 21 C 1/08, 5/12
<u>Application Date</u>	:	July 4, 1983
<u>Publication Date</u>	:	January 23, 1985
<u>Foreign Language Title</u>	:	Futtōsuigata Genshiro
<u>English Title</u>	:	BOILING WATER TYPE NUCLEAR REACTOR

Specification /521[1]

1. **Title: Boiling Water Type Nuclear Reactor**

2. **Claim**

Boiling water type nuclear reactor characterized in that fuel assemblies with a higher mean degree of concentration than those of fuel assemblies they replace are arranged on the periphery of the reactor core, and two or more types of fuel assembly having differing degrees of concentration inferior to those of said replaced fuel assemblies are arranged elsewhere in the core.

3. **Detailed Description of the Invention**

Technical Field of the Invention

The present invention relates to a boiling water type nuclear reactor.

Prior Art

The initially loaded core of a boiling water type nuclear reactor (referred to hereinbelow as BWR) is comprised of a single type of fuel assembly of a normal degree of concentration. Fuel assemblies of lowered reactivity are replaced with new fuel assemblies each time the operation cycle is updated; continuing operation permits rapid transition to an equilibrium cycle. This transition comprises cycle 1, operation with the initial core; cycle 2, operation with partially replaced fuel assemblies as described above; and so forth, such operational cycles being repeated over an extended period until a cycle, called the

---

[1] Numbers in the margin indicate pagination in the foreign text.

equilibrium cycle, is reached wherein all fuel components inside the reactor have attained a constant state. The heat characteristics of consecutive cycles are nearly identical, stabilizing once said equilibrium cycle has been reached.

In a nuclear reactor having a core similar to the one described above, the reactor is stopped upon completion of each operation cycle, the fuel assemblies whose reactivity has decreased the most are replaced with new elements, and the next cycle is engaged. Operation of the nuclear reactor is continued by repeating this cycle. It is desirable for the heat characteristics, reactivity of the reactor, cycle burnup, etc. of the transitional cycles from cycle 1 to the equilibrium cycle to be of the same degree as those of the equilibrium cycle.

Drawbacks of Prior Art

As stated above, conventional initially loaded cores are comprised of fuel assemblies of a single degree of concentration. This constitutes a drawback in that by the end of cycle 1, fuel

/522

assemblies of high reactivity are produced in large numbers, precluding fuel economy.

Moreover, it is usually necessary to change the control rod pattern once every two months in conventional BWRs. Since BWR output must be reduced at such times, there is a drawback in the form of less efficient plant utilization.

Object of the Invention

Devised on the basis of the considerations set forth above, the present invention has as its objects high fuel economy and the realization of BWRs that provide highly efficient plant utilization.

Summary of the Invention

The above-stated objects are achieved in the present invention by loading the initial core with multiple types of fuel assemblies of differing degrees of concentration according to a determined method.

Embodiments

The present invention is described in detail below. Fuel economy improves when fuel assemblies of multiple degrees of concentration are used in the initial loads of BWRs as opposed to the use of assemblies of a uniform degree of concentration. When multiple degrees of concentration are appropriately chosen, equilibrium cycle cores can be simulated to begin in cycle 1. Figures 1 and 2 show models of this state. Figure 1 shows the infinite multiplication factor ($K\infty$) of fuel at the end of the cycle when initial fuel has been loaded; Graph A of said figure shows the use of fuel of a single degree of concentration and Graph B of said figure shows the use of three degrees of concentration. Comparing the fixed proportion of fuel assemblies shown by the slanted lines, the mean $K\infty$ in Graph B of removed fuel assemblies having three degrees of concentration is smaller, making use of such fuel economically advantageous.

Figure 2 projects the typical change in burnup of replacement fuel loaded after cycle 2.

In the initial stage of burning, burnable poison is used to control the excess reactivity of the nuclear reactor, whose behavior is similar to that shown by the broken line in the graph. However, the model here has been simplified to show the case where no burnable poison is present. In this graph K∞ is found to decrease linearly with the increase in burnup.

In an equilibrium core, burning of fuel assemblies resident in the core for just N cycles progresses only during the intervals denoted in the figure by 1, 2...N. If fuel assemblies having N degrees of concentration displaying changes in K∞ identical to those of the 1, 2...N intervals in the figure are loaded in an initial core, characteristics approximating those of an equilibrium core can be obtained in the initially loaded core. Furthermore, by replacing only 1/N of the fuel assemblies in the transition cycle, an equilibrium core can be rapidly attained.

In the present invention as set forth above, in the loading of fuel assemblies of N different degrees of concentration in an initial core in which the fuel remains present for N cycles (N batch fuel) to achieve an equilibrium core, the degree of concentration of each type of fuel assembly is determined to provide a K∞ identical to that of the N batch fuel of the above-mentioned equilibrium core.

A detailed description of the effect of the present invention is given below. First, using a simple model, it will

be explained how the use of N types of fuel assembly in the present invention is more economical than the use of a single type.

An evaluation of the burnup in an initially loaded core comprised of a single type of fuel assembly will be made first. Here, the mean degree of fuel concentration will be considered equal to that of fuel assemblies in an equilibrium core simulation of N types of initially loaded fuel assemblies. The $K\infty$ of replacement fuel and initially loaded single-type fuel are given as g and h, respectively, and are considered to be identical to those shown in Figure 2, decreasing linearly with the progression of burning.

Their values at the end of a cycle k are given as:

g(k)=a.(kEc)+b (1) and

h(k)=a.(kEc)+b' (2).

Here, a, b and b' are constants, and Ec is the cycle burnup (constant).

The initially loaded fuel is removed in a proportion of fi in cycle i, and is assumed to be replaced with an equal amount of replacement fuel. The mean infinite multiplication factor of the core at the beginning of the cycle is constant (K_{EOC}), and K_{EOC} at the end of each cycle is given by the equations below:

End of cycle 2:

$K=f1\cdot g(1)+(1-f1)\cdot h(2)$

End of cycle 3:

$K=f2\cdot g(1)+(1-f1-f2)f(3)+fig(2)$

End of cycle N:

$$K = \sum_{i=1}^{n-1} fi \cdot g(n-1) + \left(1 - \sum_{i=1}^{n-1} fi\right) \cdot h(n) \qquad (3)$$

Here, in cycle (n+1), it is assumed that none of the initially loaded fuel remains.

The burnup, $E^{(f)}i$, of a single type of initially loaded fuel removed at the end of cycle i is

$$E_i^{(f)} = i\,Ec \qquad (4)$$

and the mean burnup $E^{-(f)}$ is

$$\bar{E}^{(f)} = \sum_{i=1}^{n} (fi \cdot i\,Ec) \qquad (5)$$

(however, $\sum_{i=1}^{n} fi = 1.0$)

When simulating characteristics identical to those of an equilibrium core with fuel assemblies having N degrees of concentration, the burnup $E^{(N)}i$ of initially loaded fuel removed with each cycle is

$$E_i^{(N)} = i\,Ec \qquad (6)$$

and the mean burnup E is

$$\bar{E}^{(N)} = \sum_{i=1}^{N} (i\,Ec)/N = \frac{N+1}{2} Ec \qquad (7)$$

Next a specific computational example will be given. In Figure 3, the straight line ℓ_1 on the right side shows the relation between K∞ and burnup when replaced fuel concentration was 3W/O. If the equilibrium core is assumed to have a mean burnup of about 8Gwd/st at about 3 batches, the intervals of each batch burnup are given by 1, 2 and 3. The change in K∞ of other degrees of concentration can also be approximated in the same manner by a straight line. The dependency of K∞ on the degree of

concentration at the onset of burning is shown on the left side of the same figure by the curve ℓ_2.

The degrees of concentration of initially loaded fuel required to give K∞ at the start of the cycle of each equilibrium core batch can be obtained from the curve as the degrees of concentration corresponding to K∞ at the start of the cycle. In this figure, the degrees of concentration of the initially loaded fuel elements are about 3.0, 2.2, and 1.4 W/O. If these were loaded in proportions equal to those of the number of fuel elements of each K∞ at the beginning of the cycle in an equilibrium core, the mean degree of concentration of initially loaded fuel would be about 2.2 W/O.

Furthermore, the values **a**, **b** and **b'** in equations (1) and (2) would become -0,011, 1.26, and 1.18, respectively.

The infinite multiplication factor at the end of the cycle would be about 1.05.

Figure 4A shows a comparison of the replacement ratio of initially loaded fuel in each cycle as worked out using the above model, and the case when a single type of initially loaded fuel is used. Figure 4B is a similar figure showing mean burnup. These figures show the case where all initially loaded fuel is removed not later than the end of the third cycle. As may be seen from these figures, the use of three types of initially loaded fuel in the present invention lengthens the residence time of the fuel in the reactor and increases mean burnup (by about

10%) over the case where a single type is used, clearly demonstrating the economic superiority of the present invention.

The present invention is based on the above-mentioned theoretical considerations. In the typical embodiment shown in Figure 5, control rods are denoted by a "+", and the numbers entered in the spaces denote the degree of concentration of fuel assemblies, 1 being the highest and 4 the lowest. As can be seen from this figure, fuel elements of the lowest degree of concentration, indicated by 4, are arrayed around the control rod C_1 in the center of the core, and around every second control rod C_1 above, below, left and right of said center control rod in the figure.

Said control rods C_1 serve chiefly in operation of the BWR. In the outermost part of the core are arrayed fuel assemblies of the highest degree of concentration, designated by the number 1. Fuel assemblies of intermediate degrees of concentration, designated by the numbers 2 and 3, are suitably arranged in other positions. The presence of equal numbers of fuel assemblies of degrees of concentration of from 2 to 4 is desirable.

Figure 6 shows the condition of the loaded fuel assemblies in the equilibrium cycle.

In this figure, the numbers 1-4 indicate the number of years of residence of the fuel in the core. The fewer the years of residence of the fuel, the greater its reactivity. Fuel assemblies having four years of residence and continuing to burn while having little reactivity are arranged in the outermost part

of the core. There is little leakage of neutrons from a reactor with a core of this configuration, and it is possible to reduce the total quantity of fissile material (U-235, Pu-239, etc.), ie, the amount of replacement fuel. Along the same line, if fuel assemblies having the lowest degrees of concentration are arrayed in the outermost

/524

part of the initially loaded core as well, the amount of desired fissile material can be reduced in the same manner as in the equilibrium cycle.

By contrast, in the present invention as set forth in the above description, the fuel assemblies of the highest degrees of concentration are arrayed in the outermost part of the core.

When the fuel assemblies of the lowest degrees of concentration are arrayed in the outermost part of the core, since the output of said outermost part of the core is about 1/2 the core average, said assemblies are removed in the following cycle despite their low burnup.

By contrast, in the core of the present invention, although the total quantity of fissile material in the initially loaded core is large, since the fuel assemblies of highest concentration, arranged in the outermost part of the core, maintain a suitably high reactivity through the end of cycle 1, they need not be removed in cycle 2, but can be repositioned and reused. This alone lowers the number of replacement fuel assemblies.

Figure 7 shows the method of obtaining the degree of concentration of fuel assemblies arranged in the outermost part of the core. In this figure, straight line L_1 shows the relation between the infinite multiplication factor ($K\infty$) of fuel of the highest degree of concentration and burnup (GWd/st), and curve L_2 shows the dependence of $K\infty$ at the outset of burning on the degree of concentration (W/O).

The numbers in the figure indicate intervals during which a given cycle burns. In the example shown here, the equilibrium core is reached at about batch 3 and the mean degree of concentration is about 8 Gwd/st. The degrees of concentration of fuel initially loaded other than in the outermost part of the core, obtained in the same manner as in Figure 3, are combinations of about 3.0 W/O, 2.2 W/O and 1.4 W/O. The degree of concentration of replacement fuel is 3.0 W/O.

The fissile property of fuel of the highest degree of concentration is determined so as to become identical to that replacement fuel in or after cycle 2. Said concentrated fuel arrayed on the core periphery in cycle 1; since the reactor output on the core periphery is about 1/2 of the core mean output, as shown by 1 in Figure 7, burning proceeds to about 1/2 that of cycle burnup. The equivalent $K\infty$ for the beginning of cycle 1 is obtained by extending back the straight line of interval 2 and beyond, and the value obtained is correlated with curve L_2 to obtain a degree of concentration of about 3.4 W/O.

The results of a detailed study made using the implementation code of a fuel replacement plan based on a diffusion equation wherein core axial output distribution was approximated by a cosine distribution and radial [distribution] was of a single dimension are given below.

Examples A and B below were compared for a core wherein three types of fuel assembly, ie, having degrees of concentration of 3.0 W/O, 2.2 W/O and 1.4 W/O, were loaded in nearly equal number in all but the core periphery.

In Example A, fuel of a degree of concentration of 1.4 W/O was positioned on the core periphery.

In Example B, fuel of a degree of concentration of 3.4 W/O was positioned on the core periphery.

First, in Example B, since fuel of a high degree of concentration was used, output of the core periphery was found to increase and flattening of the radial output distribution of the core was measured. As a result, there was about a 5% larger radial output peak than in the Example A core. Since the maximum linear heat rating of the fuel elements dropped and there was a large margin of fuel soundness, control rod operation during output operation was simplified and the plant operation rate rose.

Next, the length of cycle 1 was set at 12 months. After termination of the cycle, in addition to replacing about half of the assemblies having a degree of concentration of 1.4 W/O with fuel of a degree of concentration of 3.0 W/O, fuel on the core

periphery was interchanged with fuel in the center portion having a degree of concentration of 1.4 W/0. Since fuel of a degree of concentration of 3.4 W/0 had a reactivity equivalent to that of replacement fuel, the number of replacement elements at the end of cycle 1 was about half the number in the equilibrium cycle core.

The cycle 2 core, obtained upon completion of the above-described replacements, had nearly the same fuel arrangement as the equilibrium cycle core described in reference to Figure 6.

In the above procedure, burning calculations based on fuel replacement and the diffusion equation were repeated to obtain the average value of burnup on removal until all the originally loaded fuel assemblies had been removed. As a result, it was found that Example B had a mean burnup of about 16% higher than Example A. Moreover, said mean burnup was found to be about 26% higher than that obtained using a single type of initially loaded fuel of a degree of concentration of 2.2 W/0.

Since fuel of a high degree of concentration was positioned on the core periphery in Example B, the amount of U-235 used in the initial core was about 16% higher than in Example A, an increase

/525

offsetting the above-mentioned increased amount of burnup. Hence, in terms of fuel economy, there was virtually no difference between Examples A and B.

However, consideration of the cost of nuclear fuel cost should not be limited to merely the cost of the desired quantity of fissile material, but should also include the cost of shaping and processing the fuel, the cost of transporting spent fuel, the cost of reprocessing, etc. Such costs account for more than half the total expense of fuel, and are proportional to the number of fuel elements.

Accordingly, if fuel economy is determined on the basis of the cost of each fuel-cycle (nuclear fuel cost per unit of energy generated), Example B is clearly more advantageous than Example A.

Figure 8 shows another embodiment of the present invention in which fuel assemblies represented by the number 5, denoting the lowest degree of concentration, are arranged around control rods C_1 positioned in locations identical to those of control rods C_1 in Figure 5, and fuel assemblies represented by the number 1, denoting the highest degree of concentration, are positioned on the core periphery. Fuel assemblies represented by numbers 2-4, denoting intermediate degrees of concentration, are suitably arranged around other control rods. An effect identical to that of the above-described embodiment is obtained in this embodiment as well.

Effect of the Invention

As clearly set forth above, since the number of replacement assemblies is reduced during the transition period in the present invention, fuel economy is improved and a core having the fuel

arrangement and core characteristics of an equilibrium cycle core is obtained from cycle 2 on.

Furthermore, manipulation of control rods in control rod operations during output is simplified and plant utilization efficiency improves.

4. Brief Description of the Figures

Figure 1 is a graph showing both the infinite multiplication factor ($K\infty$) of fuel at the end of the cycle when initial fuel has been loaded and the proportions of initially loaded fuel elements; Figure 1A is a graph of a single degree of concentration and Figure 1B is a graph of three different degrees of concentration. Figure 2 is a graph showing the projected degree of concentration of fuel loaded after cycle 2. Figure 3 is a graph of the dependency of $K\infty$ on the degree of concentration in a specific example of the present invention. Figure 4A is a graph comparing by cycle the replacement proportion of initially loaded fuel in the above-mentioned embodiment to that of a conventional configuration; Figure 4B is a similar graph showing replaced mean burnup. Figure 5 is a type diagram of an embodiment of the present invention. Figure 6 is a type diagram of an equilibrium cycle core. Figure 7 comprises graphs showing the relation between the $K\infty$ of fuel loaded in the outermost part of an initially loaded core and burnup, the relation between said $K\infty$ and the degree of concentration, and the dependence of $K\infty$ on the degree of concentration. Figure 8 is a type diagram of another embodiment of the present invention.

Agent: Patent Attorney Goro Kikuchi /526

Figure 1

[A, on left] Proportional number of elements

[B, on left] Proportional number of elements

[B, below] Infinite multiplication factor

Figure 2

[on left] Infinite multiplication factor

[underneath] Burnup

Figure 3

[bottom, left] Degree of concentration (W/O)

[bottom, right] Burnup (GWD/ST) /527

Figure 4

[A: left] Proportional replacement of initially loaded fuel

[A; bottom] Cycle No.

[B: top, hatched] 1 type of initially loaded fuel

[B: top, plain] 3 types of initially loaded fuel

[B: left] Mean replacement burnup of initially loaded fuel (GWD/MT)

[B: bottom] Cycle No.

Figure 5

Figure 6 /528

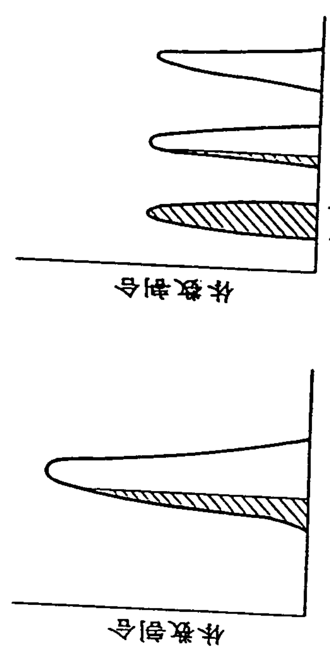
Figure 7

[bottom, left] Degree of concentration (W/O)

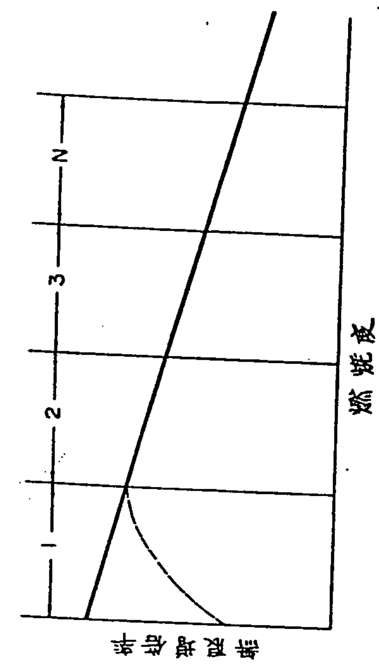
[bottom, right] Burnup (GWD/ST)

Figure 8

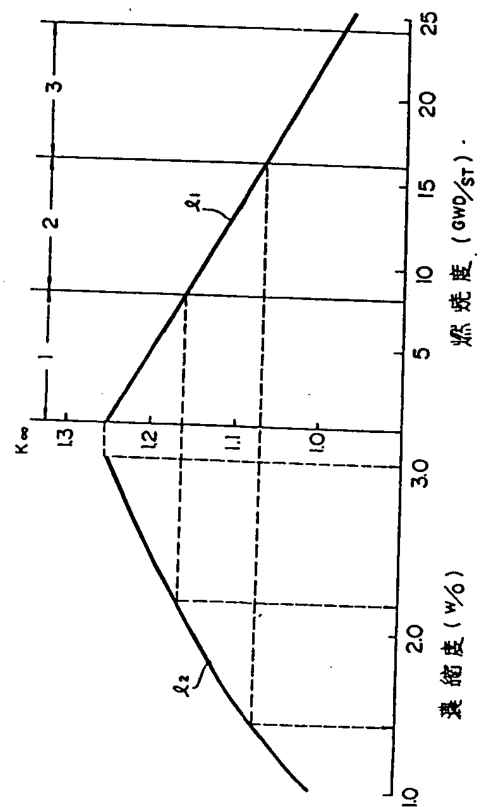
第1図


A
B
中性子束
中性子束
無限増倍率

第2図

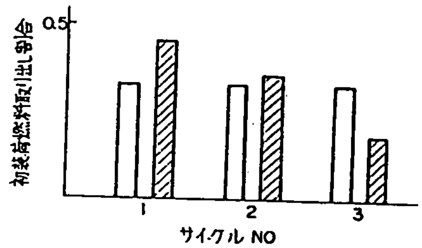

1
2
3
N
燃焼度

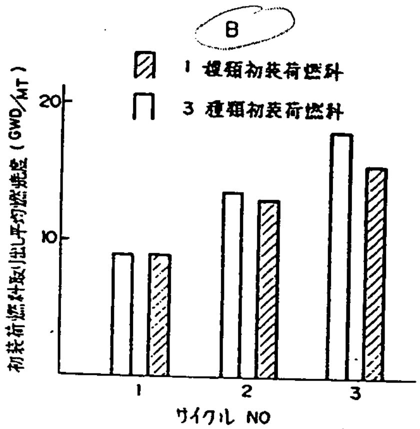
第3図


1
2
3
K∞
1.3
1.2
1.1
1.0
ℓ1
ℓ2
5
10
15
20
25
燃焼度 (GWD/ST)
3.0
2.0
1.0
濃縮度 (w/o)

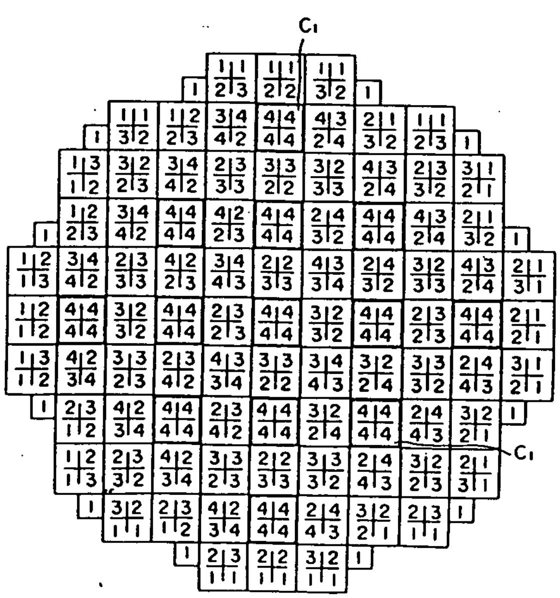
第 4 図

A

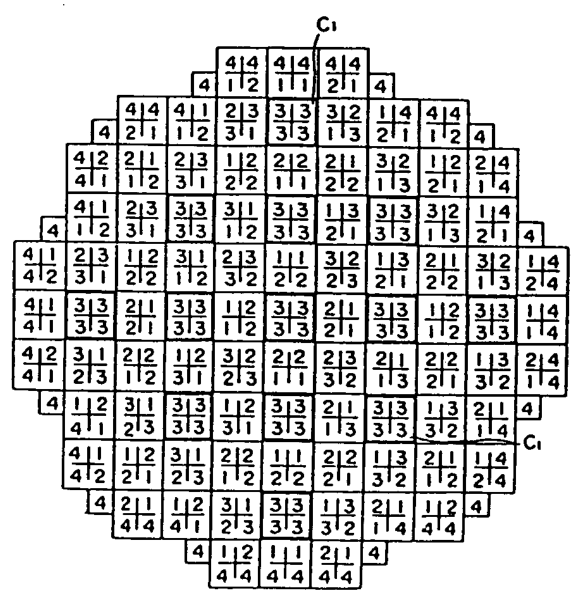

初装荷燃料取り出し割合
0.5
1
2
3
サイクル NO


B
1 種類初装荷燃料
3 種類初装荷燃料
初装荷燃料取り出し平均燃焼度 (GWD/MT)
20
10
1
2
3
サイクル NO

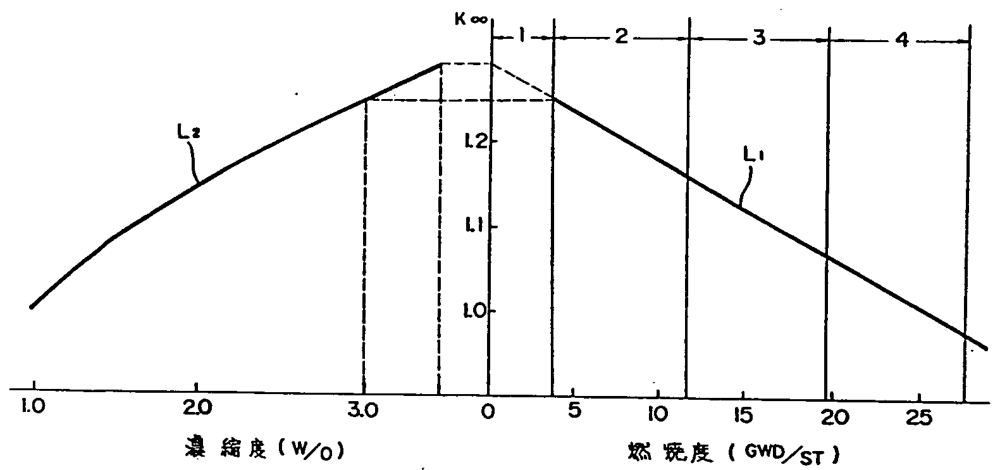
第 5 図


C1
C1

第 6 図


C1
C1

第 7 図



第 8 図